FINAL REPORT

for the

P-107A HYDROGEN LEAK METER

June 1965

CONTRACT NUMBER NAS8-5243

prepared by

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for

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SUMMARY

A major portion of the closing period of this project was directed toward fabricating and testing six (6) Flight Unit Hydrogen Leak Meters. All six units were acceptance tested and shipped in June, 1965. Each unit passed the required tests under the surveillance of a Government Source Inspector. All data was well within the required specifications. The Acceptance Test Summary Table is a tabulated summary of test results.

INTRODUCTION

A program has been conducted leading to the design, fabrication, test, and delivery of several Hydrogen Leak Meters for the measurement of hydrogen leakage in liquid hydrogen propulsion systems under contract number NAS8-5243. The overall project included the fabrication and testing of one (1) breadboard, two (2) prototypes, six (6) engineering models, and six (6) flight units. All six flight units were acceptance tested per System Test Procedure #330144.

Efforts during the last portion of the project were directed toward fabricating and testing the six flight units. These units were designed to NASA Specification #50M60079. Qualification tests were waived; however, sufficient testing was performed during the program to assure proper operation under required environmental conditions. A summary of acceptance test results has been tabulated and is included in this report. Actual test data is included in the Appendix.

The Technical Discussion section of this report covers the low flow improvement, mass flow calculations, temperature control, discussion on matching cell factors, and output adjustment availability.

TECHNICAL DISCUSSION

Low Flow Output Characteristics

Figure 2A graphically compares transfer characteristics before and after installation of the KEL-F plugs into the thermal conductivity block. As indicated, there is a significant improvement in output signal sensitivity below 150 cc/minute.

In the original design of the block, cell volume was reduced to a feasible minimum. Further reduction required insertion of cell plugs. KEL-F cell plugs were designed to fill up dead volume on each side of the thermistor bead as well as to precisely direct the mass flow toward the bead.

By minimizing dead volume, flow velocity across the bead was increased. Since the probability of molecular collision with the bead is increased, low flow sensitivity is improved. Comparing the low flow output characteristics with and without the cell plug illustrates the optimizing effect on sensitivity by reducing dead volume within the cell.

Since the bead diameter is 0.01 inches, there existed an assembly problem in precisely aligning the bead center with the port center. The problem was further complicated by the fact that the bead leads were not always taut. This allowed considerable freedom for the bead to be located over a wide diametet. Adjustment washers were used to place the bead at the center of the port hole. The manufacturer has been requested to precisely locate the bead on taut lead wires for future orders.

Mass Flow Calculations

As the result of a discussion with representatives from your facility, MSFC Specification #50M60079 (Specifications for Hydrogen Leak Meter Assembly), Sheet 4, Section 3.5.2, was corrected to specify a flow rate range of 0.015 to 2.247 mg/second rather than 0.0015 to 0.2247 mg/second. The flow rate range of 0.015 to 2.247 mg/second corresponds with the earlier prototype and engineering model requirements of 10 cc/minute to 1500 cc/minute at standard conditions.

As prescribed in the System Test Procedure (CSC #330144), the flight units were calibrated with hydrogen and helium over the range of 10 to 1500 cc/minute. Actual gas temperature and barometric pressure were recorded for each calibration run. With this data, mass flow rates can be calculated in mg/second.

At standard conditions (0°C, 1 atm.), the density of hydrogen gas is 0.09 gm/liter. The gas temperature will change radically as it passes from the inlet connector (-135°C to -250°C) to the cell block (+35°C) and then to the outlet connector (-155°C to +75°C). However, the only temperature and pressure data required to calculate mass flow are those within the Bubble-O-Meter (B-O-M) during calibration.

Volume flow rate may be corrected for water vapor pressure and converted to standard conditions by the following formula:

$$\text{Flow Rate}\left(\frac{mg}{sec}\right) = \left(\frac{cc}{sec}\right)\left(\frac{P-p}{29.92}\right)\left(\frac{492}{460 + t°F}\right)\left(\frac{.09\ mg}{cc}\right)$$

$$= \left(\frac{cc}{sec}\right)\left(\frac{P-p\ \text{in Hg}}{460 + t°F}\right)(1.478)$$

where: P = Ambient Pressure (in Hg)
p = Vapor Pressure of Water at t
t = Ambient Temperature (°F)
cc/sec = Volume Flow Rate at t and P (Bubble-O-Meter Reading)

<u>Temperature Control</u>

The internal structure of the Hydrogen Leak Meter was thermodynamically engineered to reduce thermal losses to a minimum. Operating at -155°C, the heaters continue to cycle off and on. Extended periods of operation below -155°C cause heaters to stay on continuously. The average warm-up power requirements for the six flight units is 8.8 watts at 28 VDC. The average operating power with heaters off is 2.4 watts at 28 VDC.

The cell block is thermally isolated by a KEL-F mounting pedestal. For maximum thermal transfer and isolation of the block and heat exchanger, the exchanger coils are constructed of stainless steel with KEL-F tubing at the inlet and outlet lines. The exchanger inlet and outlet coils are welded together to give maximum heat transfer. The KEL-F tubing is extended around the mounting pedestal to increase the inlet and outlet line lengths. The purpose of long inlet and outlet lines is to thermally isolate the block and exchanger.

Area type heating pads are fastened to the thermal conductivity block and heat exchanger assembly to evenly distribute the heat. Except for the two stainless steel mounting screws extending from the pedestal base to the circuit boards, the block and exchanger assembly is completely isolated thermally from the case.

The block and exchanger assembly is packed in Tipersul (fibrous potassium titanate). When perfectly dry and properly packed, the thermal conductivity (T.C.) of Tipersul is 0.25 BTU-IN/HR FT^2 F°. This material is used in the powder form.

Just prior to packing, the entire unit is placed into a temperature controlled oven for over two hours at +75°C. The powder is placed into the oven at the same time to completely bake out any moisture present.

Immediately after the baking period, the unit is packed and sealed with the cover and RFI gasket. After the safety wire has been installed, it is sprayed with a fungus resistant varnish. The varnish completely seals and protects the entire external surface except for electrical pins and internal section of the inlet and outlet connectors.

The heater circuit consists of a heat sensor, power amplifier, and heater pads. Temperature of the block is sensed by a thermistor bead imbedded into the block near the active and reference thermistors. This thermistor changes resistance with block temperature. Connected in a voltage divider circuit, a change in resistance varies the control current to a transistor. This transistor, in turn, controls current to the power switching circuit. Connected as a Darlington Amplifier, the power stage switches rapidly from full saturation to full open at a preset control current level. The power transistor was chosen for low saturation resistance to minimize heat dissipation in the transistor.

Cell Factor Matching

It was shown in Progress Report, A#6511, dated 22 March 1965 that $\frac{dE}{dT}$ for the active and reference cells can be matched by adjusting thermistor currents; i.e.,

(1) $$\left.\frac{dE}{dT}\right|_{active} = -IR\left.\frac{\beta}{T^2}\right|_{active}$$

(2) $$\left.\frac{dE}{dT}\right|_{reference} = -IR\left.\frac{\beta}{T^2}\right|_{reference}$$

where E = Voltage across Thermistor
I = Current through Thermistor
R = Resistance of Thermistor at Bead Temperature T
β = Thermistor Physical Constant

For matched cell factors:

(3) $$\left.\frac{dE}{dT}\right|_{active} = \left.\frac{dE}{dT}\right|_{reference}$$

or $$IR\left.\frac{\beta}{T^2}\right|_{active} = IR\left.\frac{\beta}{T^2}\right|_{reference}$$

letting $$\left.\frac{R\beta}{T^2}\right|_{active} = K_A$$

and $$\left.\frac{R\beta}{T^2}\right|_{reference} = K_R$$

Therefore,

(4) $$I_{active}\, K_A = I_{reference}\, K_R$$

although $K_A \neq K_R$, I_{active} and $I_{reference}$, may be adjusted to satisfy equation (4).

For the six flight units, $\frac{dE}{dT}$ was matched by selecting the current regulator resistor to force

$$\left.\frac{dE}{dT}\right|_{active} = \left.\frac{dE}{dT}\right|_{reference}.$$

For the particular cell factor of the flight units, a current in the order of 6 ma for $I_{reference}$ and 5 ma for I_{active} were required.

Output Adjustments

Output voltage adjustment potentiometers are conveniently located below the top cover. In production, these settings may be adjusted as required. For a given output sensitivity, no further adjustment is required after preset at the factory.

At final assembly, flow rate/output voltage can be adjusted over a voltage range in the order of four to six volts for 1500 cc/minute at room conditions. If required, sensitivity may be reset at any time by removing the top cover and adjusting R112. After output sensitivity is adjusted at final test, the "low flow/zero set" adjustment is trimmed to produce optimum low flow rate output characteristics.

Due to the geometric configuration of the thermal cells, the active bead and the reference bead do not perfectly match dE/dT when the cells are first purged with one gas and then flushed with another. Although the two beads will track each other with this change in thermal conductivity of the surrounding gas, there may always be a slight mismatch or offset between transfer characteristics of the two beads. This mismatch may cause as much as a 200 to 300 millivolts shift in the output. At no flow, this causes a zero shift.

With extreme care in current adjustment (trial and error process), this effect was reduced to about 10 millivolts change. With output sensitivity set at 5 VDC for 1500 cc/minute, the output is about 100 to 200 millivolts at 10 cc/minute. Therefore, precise current matching must be performed to reduce "zero shift" to 10 to 20 millivolts.

It is possible to sense a flow rate below 10 cc/minute if it were not for this inherent "zero shift" with different gases such as air and hydrogen entering the cells. Although this effect may be eliminated by precisely adjusting the thermistor currents, it is not practical to do so. A practical adjustment of thermistor currents will not normally allow repeatable operation below 10 cc/minute.

By adjusting the zero adjustment resistor R113 for air, the zero will shift more negative as molecules of hydrogen or helium enter the cell. Only a few molecules are required to cause this shift. The new zero is a negative signal; however, the output diode blocks the negative signal and the instrument will read zero until the flow increases to produce a 10 to 20 millivolt signal. Without the diode, flow rates below one cc/minute have been detected.

ACCEPTANCE TESTS

The following is a summary of data taken during acceptance testing of the six flight units:

S/N	Weight*		Heaters on Current - M.A.			Heaters Off			Power	Voltage Regulator 25 to 31V	Response	Lowest Insulation Resistance	Back
	Pound	Ounce	25 VDC	28 VDC	31 VDC	25 VDC	28 VDC	31 VDC	28 VDC Watts	Output Voltage	Time M.S.	at 100 VDC Meg Ohms	Pressure PSI
1	1	9.4	285	315	345	82	85	88	8.80	N/C	30	8K	5.6
2	1	9.9	285	314	340	80	83	85	8.80	N/C	35	460	7.6
3	1	9.6	284	314	340	81	84	87	8.80	N/C	30	20K	5.5
4	1	9.6	287	315	345	80	84	87	8.83	N/C	30	4.4K	6.2
5	1	9.4	287	315	344	85	88	92	8.83	N/C	30	34K	4.6
6	1	9.5	283	313	340	80	83	87	8.72	N/C	30	560	5.9
SPEC	2	0							9	N/S	100	50	8

*Weight of instrument with plastic connector caps installed.

N/C = No Appreciable Change

N/S = No Specifications